51. IWK
Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCEEDINGS

11-15 September 2006

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION SCIENCE

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - DEVICES AND SYSTEMS, MATERIALS AND TECHNOLOGIES FOR THE FUTURE

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische Angelegenheiten
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Susanne Jakob
Dipl.-Ing. Helge Drumm

Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag:
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilrnenau

© Technische Universität Ilmenau (Thür.) 2006

Diese Publikationen und alle in ihr enthaltenen Beiträge und Abbildungen sind urheberrechtlich geschützt. Mit Ausnahme der gesetzlich zugelassenen Fälle ist eine Verwertung ohne Einwilligung der Redaktion strafbar.

ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

51st Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
September 11 – 15, 2006

W. Nowak, R. Tarko, A. Jaglarz, J. Kozioł

Analysis of Overhead Lines Working Conditions – Case Study of Electromagnetic Coupling Effect

1. Introduction

Although electromagnetic field generated by overhead lines and substations has a wide frequency spectrum, in regular operation conditions electric and magnetic fields with 50 Hz frequency prevail. The presence of these fields is crucial for two reasons. Firstly, the influence of these fields on living organisms and the respective risks, and secondly, the technical aspect of electromagnetic compatibility stemming out of interferences. It results in, among others, induced tensions and currents in neighboring objects, also in other overhead lines. The values of induced voltages and currents depend on a number of factors, mainly: voltage level and load value in electric circuits, state of work in normal conditions, short-circuit, etc. and their spatial localization with respect to one another. It should be stressed that a low frequency of 50 Hz/60 Hz enables individual treating capacitive and inductive coupling between objects.

Capacitive interference is a result of an electrical field generated by electrical circuits. Inductive interference is caused by the existence of current circuits in the neighborhood, variable in magnetic field inducing currents and voltages in the neighboring objects. Of special importance is inductive interference in the short-circuit fault states in electrical power systems of high and extra high voltages. They are operating with a solidly grounded neutral system, where short-circuit current values several times exceed the rated current values.

The capacitive and inductive coupling effect between overhead lines is analyzed on the example of 110 kV and 220 kV power lines. They were disposed closer to each other owing to the support works. A mathematical model, verified by measurements in real conditions, became a basis for determining operation conditions of the system.

2. Characteristic of the analyzed system

The analyzed system (fig. 1) is made of two overhead power lines:

1) nominal voltage of a system of 110 kV between substations KLI and POL,
2) rated voltage of 220 kV between substations KLI and NIZ.

These power lines are conducted between towers nos. 485 and 398 on common supports with a horizontal conductors configuration (fig. 2). The 220 kV power line KLI – NIZ starts in the switchgear of the 220 kV substation KLI. Its total length between towers nos. 502 and 398 is 32,211 m. At present, the power line KLI – NIZ is permanently out of operation and out of voltage. The jumpers of the power line are dismounted on towers nos. 502, 485 and 398. It has a permanent grounding on towers nos. 501, 398 and 485 (fig. 1).

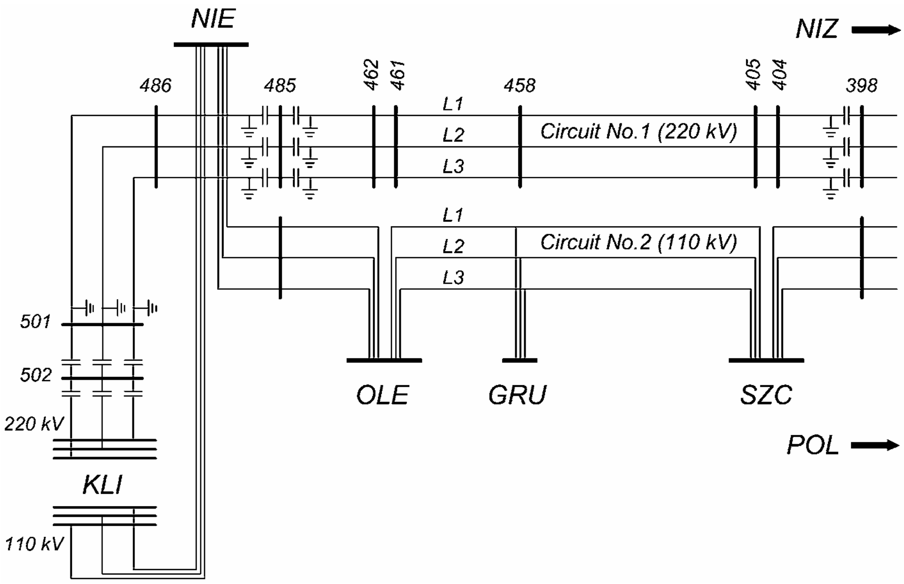

Fig. 1. Scheme of the analyzed system

Fig. 2. 220 kV power line KLI – NIZ and 110 kV power line KLI – POL on common supports

The 110 kV overhead lines configuration KLI – POL consists of four sections (fig. 1): transmission lines KLI – NIE, NIE – OLE, OLE – SZC with taped tee off substation GRU, and line SZC – POL. In the analyzed system the towers nos. 485 and 398 get closer to the 110 kV circuit KLI – POL with the inoperational 220 kV transmission line KLI – NIZ, being a result of disposing conductors of the same lines on common supports. As far as electromagnetic interference of 110 kV circuit on 220 kV circuit is concerned, four characteristic sections can be distinguished:

1) a section of transmission line NIE – OLE 7224 m long,
2) a section of line OLE – GRU-SZC 1297 m long,
3) a section of line OLE – GRU-SZC 15549 m long,
4) a section of line SZC – POL from the tower no 404 to the tower no 398; 2196 m long.

The total length of closing is 26266 m, where the total length of the 220 kV line between towers nos. 485 and 398 is 26876 m.

3. Mathematical model

Phase conductors of a transmission line 2 under operating voltage, produce an electric field in the surrounding space. When the phase conductors of transmission line 1 are not grounded, they gain some potential with respect to the ground. As a result of electric coupling (e.g., [2, 3, 4]) tension to ground U_1, U_2, U_3 is generated, as shown in a scheme in fig. 3. In the case of conductors subjected to them, their potential is equal to zero, and the discharging currents to ground I_1, I_2, I_3 determine the current efficiency interference in the aspect of potential danger of an electric shock.

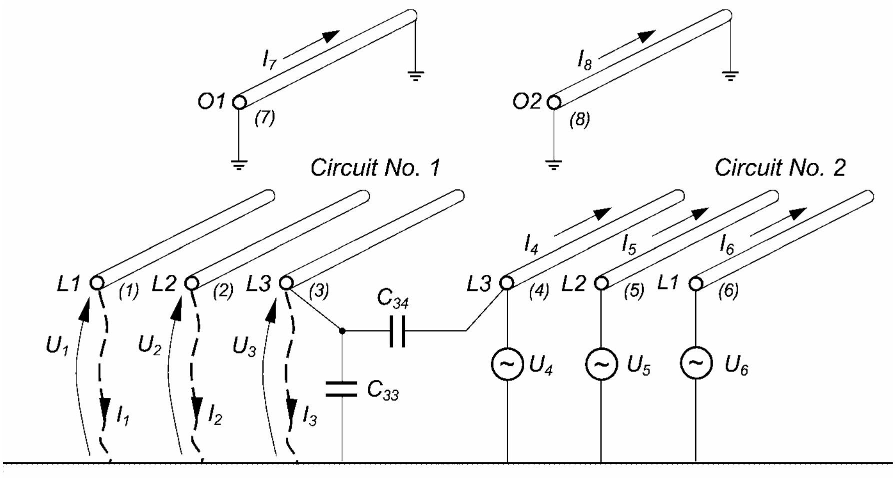

Fig. 3. Substitution scheme of capacity interference
C_{ii} – self capacitance (line to ground), C_{ij} – mutual capacitance (line to line)
$i = 1, 2, \ldots, 8$, $j = 1, 2, \ldots, 8$, $i \neq j$

The magnetic interference is caused by a magnetic field produced by currents in the conductors of the circuit 2. As a result of the coupling through mutual inductance (fig. 4) electromotive forces E_1, E_2, E_3 are induced along phase conductors of circuit 1. Their values depend on operating currents in the conductors of circuit 2, spatial array of the conductors and length of the closing section. Another important influence is that of ground wires and the neighboring objects conducting current. In the case of bi-sided grounding of the conductors of circuit 1, currents I_1, I_2, I_3 flow in the earth return loops [1]. Their values result from the induced electromotive forces and self impedances of earth return loops.

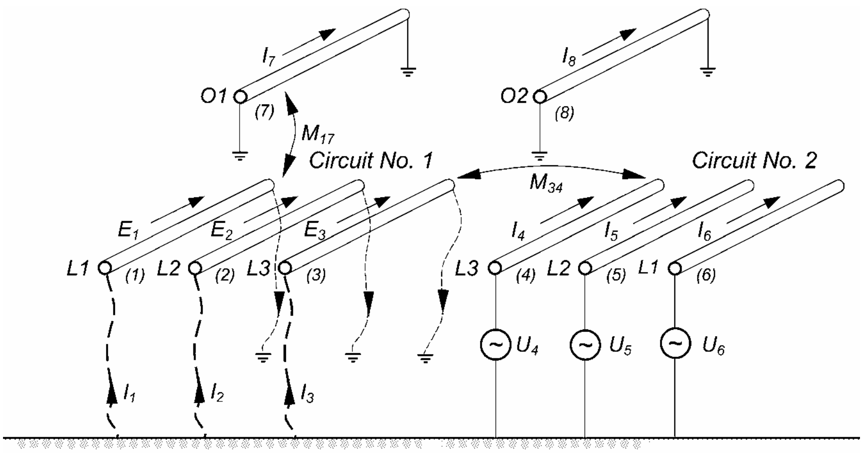

Fig. 4. Substitution scheme of magnetic interference
M_{ij} – mutual inductance i = 1, 2, ... 8, j = 1, 2, ... ,8, $i \neq j$

From the point of view of protection against electric shock, induced tensions can be treated as touch voltages, i.e. differences of potential between two points, touched simultaneously with both hands, or a hand and a foot. Such a situation can be encountered during mounting or exploitation works. When a man touches two points, with touch voltage between, the touch-current runs through the body and touch voltage appears on its impedance. Generally, the low reactance of human body is ignored and resistance of 1 kΩ is assumed for the analysis of safety conditions.

For the analyzed configuration of 220 kV KLI – NIZ and 110 kV KLI – POL lines (fig. 1), a model for a computer program *EMTP–ATP* was worked out. A block diagram of part of the model for a section between towers nos. 398 and 485 is presented in fig. 5. Overhead line models are an important part of the program *EMTP–ATP*, which predestines it for the analysis of electromagnetic interference [5, 6]. For the analyzed interferences with 50 Hz frequency, only a Π-type two-terminal-pair network capacitively and inductively coupled can be assumed, where parameters are determined by a program on the basis of typical line-design data.

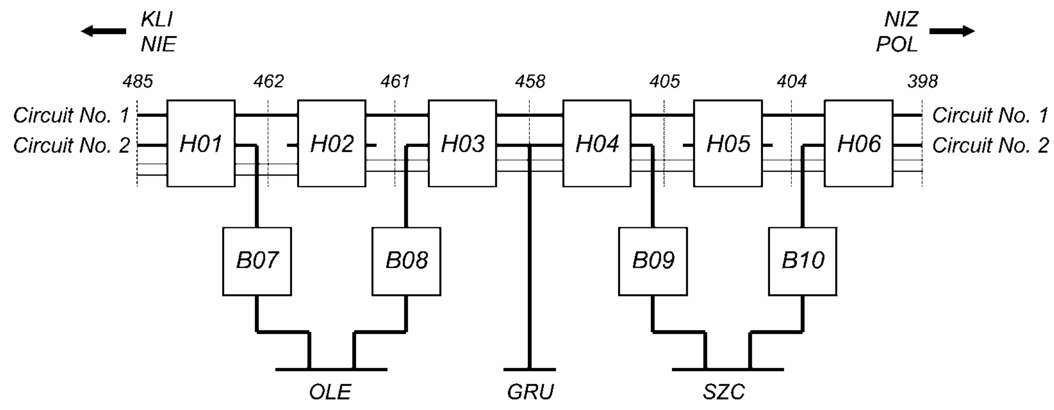

Fig. 5. Bloc diagram of part of the model for program *EMTP – ATP* of a configuration as in fig.1: *H* – double circuit line, eight-conductor line, on H-series support, *B* – single circuit line, five-conductor line, on B-series support

Apart from this, normal and failure states can be easily simulated and represented, e.g. short-circuits. This results in efficient and reliable evaluation of the predicted induced voltage and current values.

4. Analysis of interferences in real conditions

The correctness of the mathematical model was verified by comparing obtained values with values measured in real conditions (fig. 6). The scope of the analysis covered measurement of induced voltages and currents in circuit 1 as a result of capacity and magnetic interference of circuit 2. The capacity interference was analyzed after removing the groundings from tower no. 485 (on the side neighboring with tower no. 484) and from tower no. 398 in circuit 1. Inductive interferences were measured after installing grounding on tower no. 398 in circuit 1. The measurement of induced tensions and currents were made at a measurement station at tower no. 485. An electrostatic kilo-voltmeter was used for measuring capacity interference. Currents were measured with a laboratory ammeter, and discharging current with a resistor 1 kΩ. In the course of measurements the voltage and current in circuit 2 were registered.

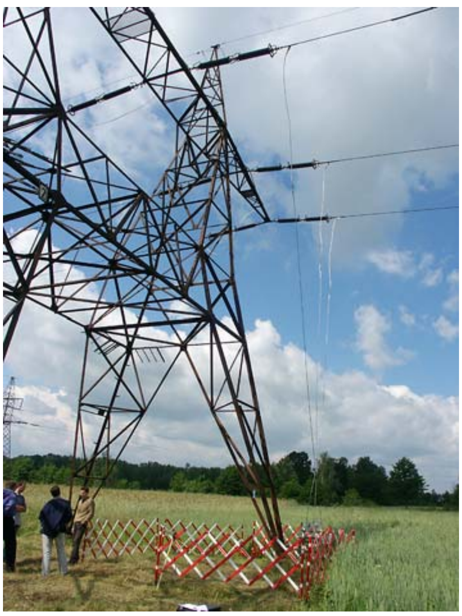

Fig. 6. Measurement station at tower no. 485

During measurement, a unidirectional energy flow was induced in the circuit 1 from the substation SZC (at the side of substation POL) to the substation KLI. The obtained results of specific interferences are presented in table 1. There are also results of calculations obtained with the use of a model worked out for the program *EMTP–ATP*.

Table 1. Measured and calculated induced tensions and currents

Parameter	Phase	INTERFERENCE			
		CAPACITY[1)]		MAGNETIC[2)]	
		measurement	calculation	measurement	calculation
Voltage to ground of phase conductors of circuit 1	L1	1.50 kV	2.04 kV	21 V	23 V
	L2	2.80 kV	3.35 kV	23 V	31 V
	L3	7.70 kV	8.90 kV	45 V	65 V
Ground current in phase conductors of circuit 1, after grounding at measurement station (tower no. 485)	L1	0.10 A	0.07 A	0.88 A	0.48 A
	L2	0.18 A	0.14 A	1.20 A	0.88 A
	L3	0.52 A	0.57 A	2.30 A	3.23 A
Ground current flowing through a grounding resistor R = 1 kΩ	L1	0.10 A	0.13 A	15 mA	23 mA
	L2	0.18 A	0.22 A	19 mA	31 mA
	L3	0.52 A	0.59 A	37 mA	55 mA

[1)] grounding jumpers dismounted from towers nos. 398 and 485 in circuit 1
[2)] grounding jumpers dismounted from tower no. 485 in circuit 1; grounding jumpers mounted on tower no. 398

5. Analysis of exploitation conditions

The analyses confirmed usability of the model and its applicability to further analyses targeted at determining:

— average annual values of touch voltage and current in phase conductors of line KLI – NIZ in circuit 1,

— average annual values of power and energy losses in phase conductors of line KLI – NIZ in circuit 1,

— values of inductive induced current in phase conductors of circuit 1 for selected cases of short-circuit faults in circuit 2.

This task can be realized when the statistical values are known (average values, distributions, etc.) related with load current in the operating circuit. Accordingly, annual changes of loads were analyzed in the specific sections of circuit 2 in the successive years. Functions of one of the annual loads of selected sections of circuit 2 KLI-NIZ are plotted in fig. 7. For analyzing the mutual relations between changes of load values in the specific sections, a correlation analysis of these functions was made. It proved that load values of specific sections of the circuit are dependent variables.

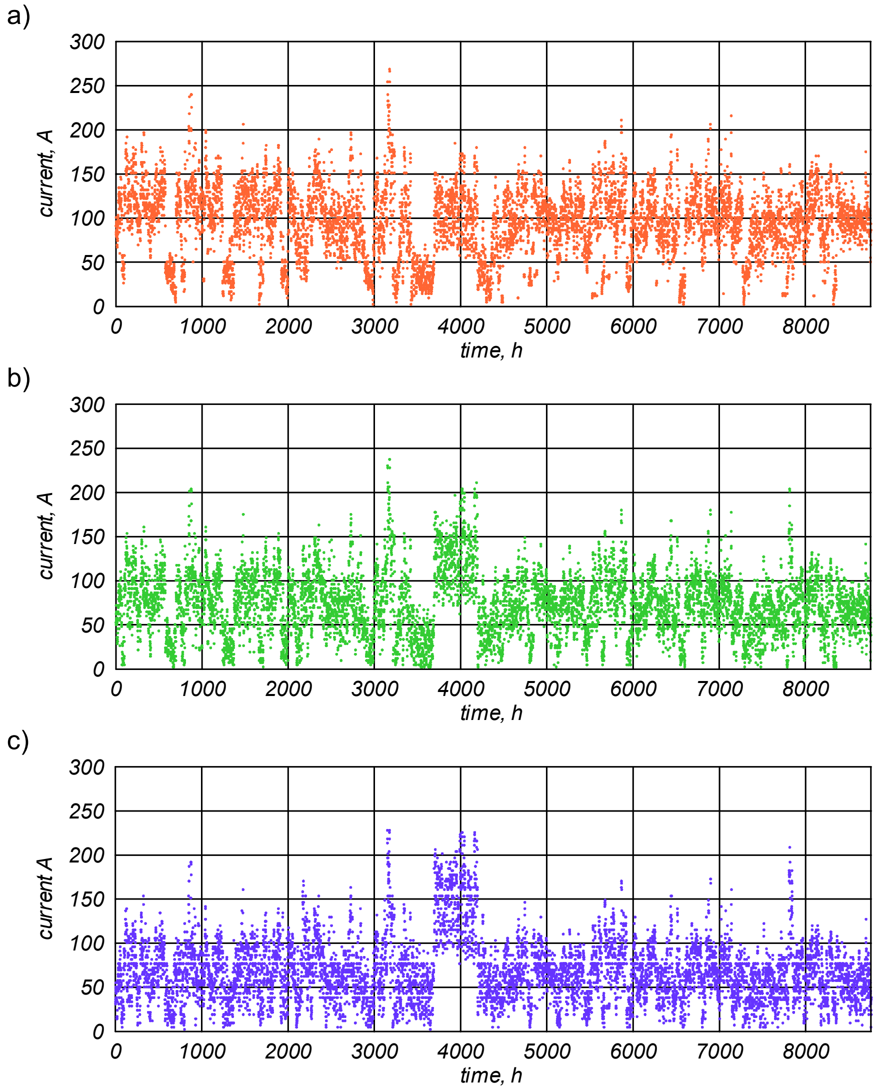

Fig. 7. Annual load of selected sections of 110 kV line: a) SZC – OLE, b) OLE – NIE, c) NIE – KLI

The results of analysis of induced voltages in specific phases of circuit 1, induced currents and touch currents obtained for highest admissible voltage of the system of 123 kV and average annual operation loads in circuit 2 were analyzed (table 2). Three exploitation variants were considered:

— variant I – bi-sided grounding of circuit on towers nos. 398 and 485,
— variant II – one-sided grounding of circuit 1 on tower no. 398 or 485,
— variant III – ungrounded circuit 1.

The results of calculations of annual average power and energy losses in circuit 1. They result from the coupling with circuit 2. For comparison's sake, the evaluated losses in overhead ground wire in a section between towers nos. 398 and 485 are also tabularized. Moreover, the analysis reveals that introducing additional grounding of phase conductors in circuit 1 does not result in any significant changes in the power and energy losses in the analyzed section.

Table 2. Average annual values of induced voltages and touch currents

Parameter	Phase	Variant I	Variant II	Variant III
Voltage between phase conductors of circuit 1 and ground	L1	–	47 V	2093 V
	L2	–	65 V	3442 V
	L3	–	136 V	9158 V
Induced currents and double-side grounded conductors of circuit 1	L1	0.360 A	–	–
	L2	1.368 A	–	–
	L3	7.506 A	–	–
Touch current at ungrounded end of circuit 1	L1	–	47 mA	132 mA
	L2	–	65 mA	222 mA
	L3	–	135 mA	612 mA

Table 3. Average annual power and energy losses in circuit 1 owing to coupling with circuit 2

Conductor	Power losses	Energy losses
Phase L1 of circuit 1	2 W	18 kWh
Phase L2 of circuit 1	28 W	245 kWh
Phase L3 of circuit 1	722 W	6325 kWh
Total losses in circuit 1	**752 W**	**6588 kWh**
Ground wire O1	3 W	26 kWh
Ground wire O2	11 W	97 kWh
Total losses in ground wire	**14 W**	**123 kWh**
TOTAL losses in circuit 1 and ground wire	**766 W**	**6711 kWh**

Table 4. Values of induced currents in double-side grounded section of circuit 1 in short-circuit conditions in circuit 2

Fault	Current I_k''	Phase L1	Phase L2	Phase L3
Symmetrical	2775 A	20 A	55 A	248 A
Line-to-line L1 – L3 L2 – L3 L1 – L2	 2286 A 2345 A 2340 A	 10 A 3 A 8 A	 33 A 26 A 10 A	 202 A 165 A 44 A
Double line to ground L1 – L3 L2 – L3 L1 – L2	 2284 A 2464 A 2464 A	 148 A 159 A 168 A	 160 A 191 A 176 A	 250 A 392 A 321 A
Single line to ground L1 L2 L3	 1737 A 1752 A 1734 A	 210 A 212 A 218 A	 218 A 228 A 253 A	 307 A 344 A 471 A

The calculated values of currents in double-sided grounded phase conductors in circuit 1 in the short-circuit current conditions in circuit 2 are presented in table 4. The presented results refer to symmetrical fault, line-to-line fault, double line to ground fault and single line to ground fault occurring in the tower no. 485 of the analyzed system.

6. Conclusions

Electromagnetic interference in the form of capacity couplings and magnetic couplings occurs in the analyzed configuration. At present, in regular exploitation conditions, jumpers on towers nos. 485 and 398 are dismounted and the ends of phase conductors of circuit KLI – NIZ are double-side grounded. In this situation only magnetic interference occurs, in the course of which induced currents are flowing in the closed earth return loops of phase conductors.

Magnetic interference and current induction in circuit KLI – NIZ cause additional energy losses. Ungrounding of only one end of the circuit (tower no. 485 or 398) eliminates this effect. The exploitation conditions significantly change, and danger of an electric shock additionally appears. Ungrounding of both ends of circuit KLI – NIZ (towers no 485 and 398) completely eliminates magnetic interference, and so the energy losses. However, the capacitive interference appears and the induced voltages create a considerable electric shock hazard.

The analysis also revealed that in the exploitation of the circuit KLI - NIZ magnetic short-circuit currents have to be accounted for, especially in the case of single line to ground and double line to ground.

Owing to the limited possibility of recovering new space for power lines, the issue of their mutual interference will play more and more prominent role in the future. Development of devices and the existing routes for producing multiple circuit lines of various voltage levels installed on common supports of overhead lines is an alternative.

REFERENCES

[1] Krakowski M.: *Obwody ziemnopowrotne*. WNT, Warszawa 1980

[2] Nowak W.: *Model analityczno–numeryczny oddziaływania linii wysokiego napięcia na sieć trakcji kolejowej*. Rozprawa doktorska, Wydział Elektrotechniki, Automatyki i Elektroniki Akademii Górniczo-Hutniczej, Kraków 1995

[3] Piłatowicz A.: *Oddziaływanie obwodów elektroenergetycznych na obwody telekomunikacyjne*. WNT, Warszawa 1975

[4] Szymański G.: *Symulacja cyfrowa niebezpiecznych oddziaływań stacji i linii wysokich napięć*. Wyd. Politechniki Poznańskiej, Poznań 1998

[5] *Alternative Transients Program. Rule Book.* Canadian/ American EMTP User Group, 1987–92

[6] *Electromagnetic Transients Program. Theory Book.* Bonneville Power Administration, Portland, Oregon, 1995

Authors:

Dr. Eng. Wiesław Nowak
M.Sc. Rafał Tarko
AGH University of Science and Technology, Al. Mickiewicza 30
30-059 Kraków
Phone: (4812) 617-28-26
Fax: (4812) 634-57-21
E-mail: wiesio@agh.edu.pl, rtarko@agh.edu.pl

M.Sc. Andrzej Jaglarz
M.Sc. Jan Kozioł
ENION S.A., Branch in Tarnow - Zakład Energetyczny Tarnów, Lwowska Street 72-96B
33-100 Tarnów
Phone: (4814) 631-16-00
Fax: (4814) 621-61-17
E-mail: andrzej.jaglarz@tarnow.enion.pl, jan.koziol@tarnow.enion.pl